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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

SIGNIFICANCE OF SPECIFIC LUBRICANT TESTS

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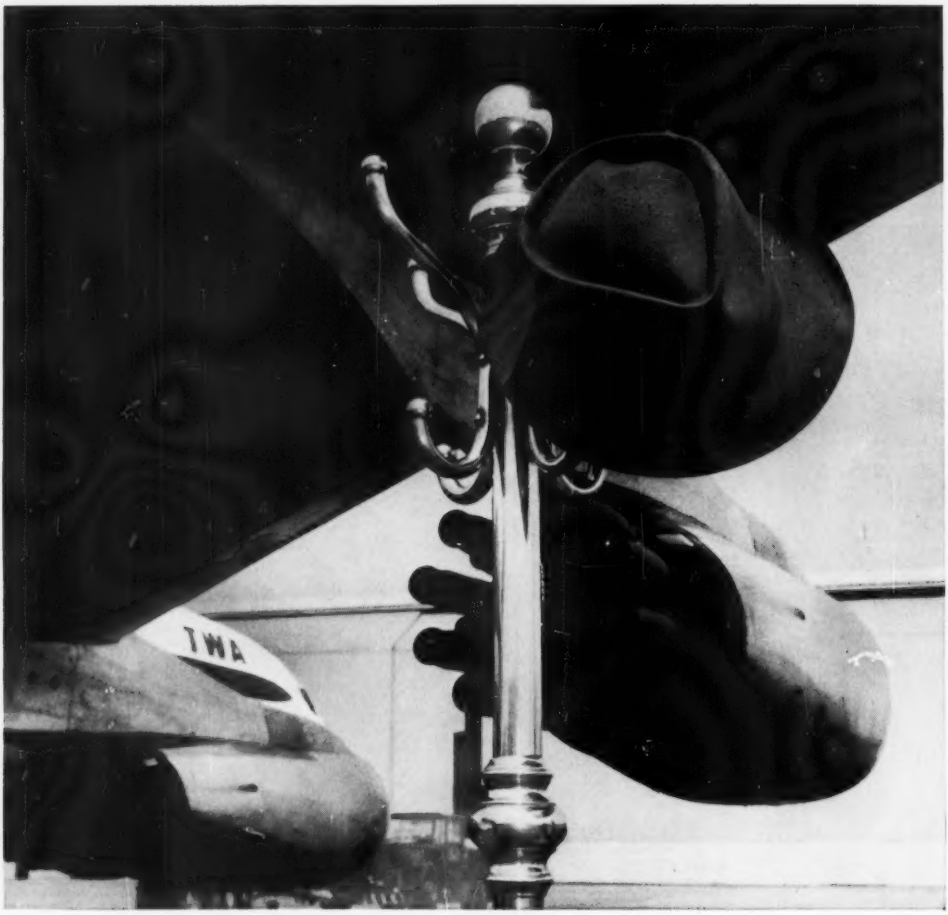

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Significance of Specific Lubricant Tests

MANY users of petroleum products have seen laboratory test reports on a lubricant consisting of a series of tests with numerical values. These are usually followed by the petroleum technologist's interpretation of the condition of the sample tested and whatever conclusions can be drawn regarding the specific problem at hand on the basis of the test results.

Several previous issues of this publication[1,2,3,4,5,6] have covered various types of analytical tests employed in the petroleum laboratory and discussed their significance.

As a continuation of this series, this issue will discuss the significance of the following tests: water, insolubles, sulfur, copper strip corrosion, aniline point, interfacial tension, dielectric strength, and turbine oil emulsion.

WATER

The old saying that "water and oil do not mix" is, with some exceptions, a good rule of thumb insofar as lubrication of machinery is concerned. It is difficult, however, to keep a lubricant completely moisture-free under normal usage. The amount of water which can be tolerated in the oil therefore depends upon the type of unit in which it is being used.

Rolling Mills

There are many applications where the presence of large amounts of water in the oil can readily occur. This situation frequently prevails in the rolling of steel.[7] This industry employs very large machines with correspondingly large bearings. Any water which enters the bearings must be removed from them by the oil. The oil returned from these bearings, particularly if their seals are not in the best condition, will frequently contain upwards of 10% water. As long as this water can be separated, usually by settling, before returning to the bearings no one is overly concerned. Providing no change is made in the water spray pattern on the rolling mill, the water content of the return oil is a good indicator of the condition of the bearing seals. These seals, it must be remembered, are not only to keep out the water but also dirt and mill scale which could cause damage and consequent down time on the unit. If the oil going back to the bearings contains more than a few tenths of 1 per cent water, it indicates either insufficient settling time or contamination of the oil with such emulsion-forming materials as oil oxidation products, soluble oil, or heavy duty type crankcase oil. In the first instance, either additional settling facilities would be required or the water

1 "Lubricating Oil Analysis" Magazine Lubrication, January 1955
2 "Grease Analysis" Magazine Lubrication, January 1956
3 "Microchemistry In Lubricating Oil Analysis" Magazine Lubrication, January 1957
4 "Instrumental Analysis of Petroleum" Magazine Lubrication, January 1958
5 "Petroleum Laboratory Investigations" Magazine Lubrication, March 1958
6 "Analysis of Deposits" Magazine Lubrication, January 1959
7 "Steel Mill Lubrication" Magazine Lubrication, October 1958

Figure 1 — Hydraulic spool valve showing severe rusting due to accumulation of water in a hydraulic oil that did not contain an effective rust inhibitor.

content of the return oil reduced either by renewal of seals or rearrangement of the water spray. In the second instance, the cause of the poor separation would have to be determined and corrected and possibly an oil change made on the unit.

Steam Turbines

Most machinery either does not come into contact with excessive amounts of water or is so designed as to effectively prevent entry of more than small amounts. For example the modern steam turbine[8] has very elaborate labyrinth sealing glands to keep the high pressure steam from contacting and condensing in the circulating bearing oil. Normally therefore the oil remains in clear condition and the moment it becomes cloudy, either a leaking gland or a cooling water leak, or a defective centrifuge can be suspected. In the case of an ocean-going turbine vessel, the water separated from the oil sample can be tested with silver nitrate. If a cloudy precipitate forms, sea water contamination from a leaky oil cooler is indicated while if it remains clear, the sealing glands and centrifuge should be checked. In general, about 0.2% water can be tolerated in a turbine for a period of time although the question of rust must always be considered and particularly if a rust preventive turbine oil is not being used. If sufficient rust forms and drops into the circulating system, strainer clogging with subsequent bearing oil starvation can occur as well as governor malfunctioning. Continuous operation of the centrifuge is advisable anytime the water content of a turbine oil exceeds 0.1% and the system should be thoroughly checked to eliminate the source of water entry.

Hydraulic Systems

The water content of hydraulic systems will, under some circumstances, reach and exceed 0.1%. Where the hydraulic system is not liable to direct water contamination, this is usually due to "breathing" of the tank and condensation of atmospheric moisture. In the case of small systems it is usually advisable to drain the oil and replace with a fresh charge. This is good insurance since any rust formed on the close fitting parts of a hydraulic system can cause expensive damage and downtime. Figures 1 and 2 show the damage which can occur to hydraulic system parts that are subjected to excessive amounts of water. In large systems, settling and centrifuging, if available, should be resorted to, and the use of a rust preventive oil is always advisable.

Engine Crankcases

It is not unusual to find water in the crankcase oil of internal combustion engines. Its presence is generally due to either condensation of water from blowby gases or leakage from the cooling system. Condensation is most frequently encountered during cold weather in association with short trips or prolonged idling in automotive applications, and because of low cooling water temperatures in stationary units. In both instances, the engine oil never reaches a high enough temperature to evaporate the water condensed in the crankcase. The water content of the crankcase oil may vary between 0.1 and 0.2% and in itself is not cause for immediate alarm, however it usually combines with fuel soot and other oil contaminants to form potentially-dangerous low temperature sludge. Installation of high temperature cooling system thermostats, reduced idling and more frequent oil changes will avoid the accumulation of excessive amounts of water in the oil systems of these units. When the crankcase oil of an internal combustion engine contains more than 0.5% water, a cooling system leak should be suspected immediately.

[8] "Electric Power-Steam Turbine Lubrication", Magazine Lubrication, June 1952

If the cooling system is protected with an ethylene glycol type anti-freeze, it is advisable to test the oil for glycol. A negative indication, however, is not decisive since ethylene glycol will react with certain constituents in the crankcase oil and settle in the form of sludge. Accordingly spectrographic analysis should also be made. If boron, a common ingredient of commercial anti-freezes is found in the water it is strong evidence that the water originated from the cooling system and the engine should be inspected immediately for a leak.

Since most used heavy duty type engine oils are black, it is difficult to obtain a water determination by centrifuge on samples originating therefrom. Water by distillation is usually used for this purpose and is sufficiently accurate to distinguish between 0.1% and 0.5% water content.

Electric Transformers

In some applications, it is extremely important that the oil be virtually water-free. Large electrical transformers for example are filled with oil which serves both as an insulating medium and as a coolant for removing the heat generated in the windings and core. The presence of very small amounts of *free* water, that is more than 100 parts per million, will seriously lower the insulating ability of the oil which could lead to "flashovers" (internal short circuits) in high voltage transformers. It should be noted that emphasis was placed on "free," i.e. undissolved water. An oil at a given temperature can dissolve 50 parts per million of water and still be clear and have excellent insulating qualities. At a lower temperature, however, the same oil with the same total amount of water will be hazy and have poor insulating qualities. This illustrates the well known phenomenon that the solubility of water in oil decreases as the temperature decreases and that some of the water which was dissolved at a higher temperature will drop out of solution and remain suspended as very fine droplets of "free water" throughout the oil if the temperature is dropped. In transformer oils this phenomenon becomes critical around the 100 p.p.m. water content level, consequently it is customary to circulate such an oil through a portable paper filter or blotter press to reduce its water content to a non-critical level.

Refrigeration Systems

Although hermetically sealed, refrigeration systems are also very sensitive to the presence of small amounts of water. Systems which are so contaminated are particularly prone to corrosion and to orifice icing. The problem is usually handled by inserting a full-flow dehydrating unit in the refrigerant line and renewing it as required. Since these extremely small amounts of water are not readily determined by either of the two previous methods noted, a very sensitive procedure known as the Karl Fischer method is employed.

Other Machinery

Gross water contamination may be expected with

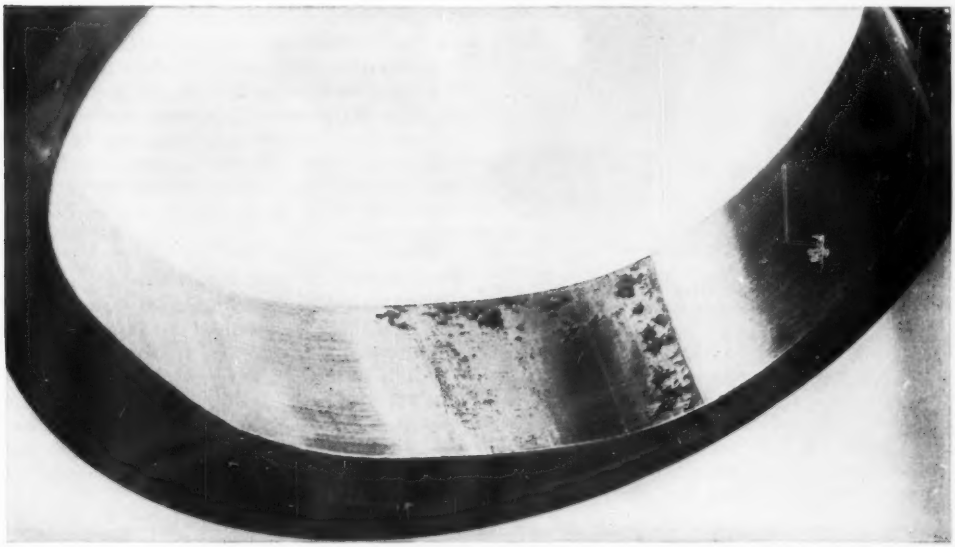

Figure 2 — Cam ring from vane type hydraulic pump rusted due to moisture in a hydraulic oil that did not contain an effective rust inhibitor.

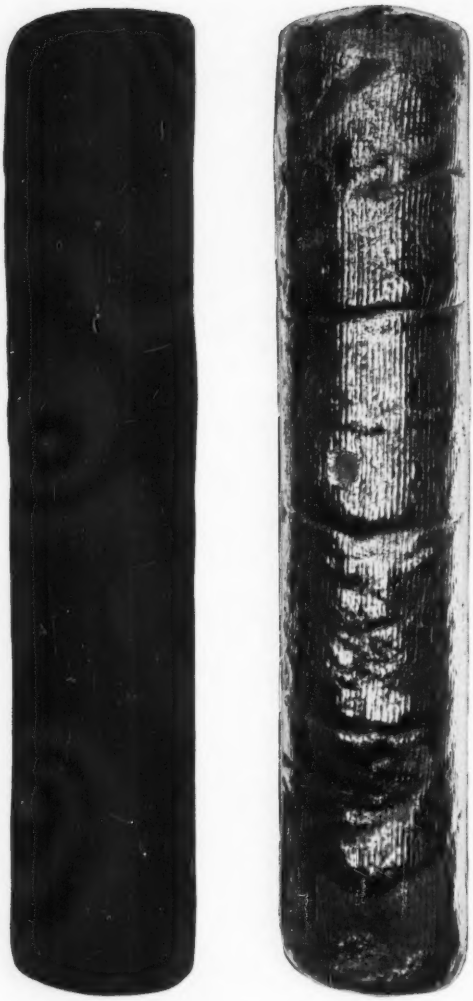

Figure 3 — *Left Picture:* "Sock" type filter removed from an engine using oil containing only 0.1% of pentane insolubles. *Right Picture:* Similar filter removed from an engine using oil with 0.5% of pentane insolubles.

other types of machinery which come into contact with large amounts of water. Some additional examples of these are mechanical coal miners,[9] paper machines,[10] and rolling mill reduction gear cases.[11] Determination of water and sediment by means of a centrifuge is an excellent procedure when large amounts of water are present.

[9] "New Developments in Underground Mining Machinery", Magazine Lubrication, June 1956

[10] "Paper Mill Lubrication", Magazine Lubrication, March 1953 and April 1958

[11] "Steel Mill Lubrication", Magazine Lubrication, October 1958

It can, therefore, be seen from the foregoing discussion that while water is usually not desirable in an oil filled system, it can be tolerated up to certain levels dependent upon the type of application that is under consideration.

INSOLUBLES

There is hardly a circulating oil system in existence which is not liable to contamination by oil-insoluble material. Water, which is essentially oil insoluble, was covered in the previous section. This section will deal primarily with particulate matter which is insoluble in oil.

Precipitation Number

A test which is frequently used to evaluate the amount of suspended matter in clear unoxidized circulating oils such as turbine and hydraulic media is Precipitation Number. Since it is a volumetric test, it has relatively poor reproducibility which makes the establishment of general numerical guides difficult. Its greatest utility lies in the fact that it gives a visual indication of the approximate amount and character of the insoluble suspended material which may be present in an oil. For instance, a Precipitation Number of 0.1 (1% by volume of insolubles) on a turbine or hydraulic oil with the precipitate consisting primarily of fibrous material would serve as a warning that the strainers in the unit should be checked frequently to avoid clogging and that the centrifuge should be operated continuously to remove this material from the oil. The test is also useful on a comparative basis for "before and after" oil samples from a centrifuge or filter to determine the unit's efficiency for insolubles removal.

Precipitation Number has occasionally been used in connection with used internal combustion engine oils. The values obtained, however, are difficult to interpret since as previously mentioned, the test is volumetric and variations in the nature of the contaminants will cause varying degrees of "packing" in the tube which in turn could cause inconsistent interpretations.

Pentane and Benzene Insolubles

Pentane and Benzene Insolubles are frequently used to evaluate the dissolved and dispersed solids in used diesel engine oils. Precautions must be taken with this method, however, since some difficulty may be experienced in precipitating all the solid suspended matter out of highly detergent oils. When used with mildly detergent oils and straight mineral oils, the method provides a practical means for evaluating the used oil.

Normal Pentane Insolubles

Normal Pentane Insolubles is the insoluble matter which can be separated from a dilute solution of oil

in n-pentane. This material includes the solids which may deposit in quiescent locations or are removed by the engine's filter, and also resinous materials which may deposit as lacquer on hot engine parts. As a general guide when a used oil sample from a railroad or stationary diesel engine contains 0.3% pentane insolubles, a filter change should be made. The left picture of Figure 3 illustrates a filter element obtained from an engine whose oil contained approximately 0.1% pentane insolubles. The right hand picture of Figure 3 illustrates a similar filter element taken from an engine whose oil contained approximately 0.5% pentane insolubles. It is obvious from the condition of this latter filter that a filter change is necessary. When the level reaches 1% or more, immediate steps should be taken to change the oil and change the filters.

Benzene Insolubles represent that portion which is attributable to dust, dirt, metallic wear, and fuel soot. A value of 0.2% would indicate the desirability of a filter change.

The numerical difference between Pentane Insolubles and Benzene Insolubles is a measure of resinous substances called Insoluble Resins. Insoluble resins are composed almost entirely of fuel and oil oxidation products and (if an additive oil is being used) spent additive. The greater the amount of insoluble resin present, the greater the likelihood that varnish will begin to form in the engine. The heavy varnish deposit on the piston shown in Figure 4 is indicative of what can occur when oils having a high insoluble resin content are continued in use. In railway service a value of 0.3% insoluble resins would indicate the desirability of an oil change. If the insoluble resins content of the oil rises very rapidly after a comparatively short service period it is indicative that the engine may be running hot or the lubricating oil coolers may need cleaning.

In connection with the previously noted approximate limits, it should be pointed out that when coagulants are used in the procedure, the resultant values will be substantially higher and the suggested limits would not be applicable.

Benzene – Methyl Ethyl Ketone Insolubles

Another solvent insoluble procedure using a mixture of Benzene and Methyl Ethyl Ketone has been employed for determining the insoluble content attributable to dust, dirt, metallic wear, and fuel soot in used highly-detergent crankcase oils from both diesel and gasoline internal combustion engines. The carbon content of these insolubles which represents fuel soot is subsequently determined and reported as "Free Carbon". A value of 0.5% free carbon on a used MIL-L-2104A type detergent crankcase oil would suggest a filter change while 1% would indicate an oil change would be necessary. Figure 5 shows an engine oil pan containing a heavy accumulation of carbonaceous matter which was deposited from an oil that contained 1.3% fuel soot.

The combustion process in gasoline engines is inherently cleaner and as a result there is seldom any requirement to be concerned with free carbon content.

SULFUR AND COPPER STRIP CORROSION

Depending upon the intended use of the oil, the presence of sulfur in lubricating oils may in some cases be desirable, while in others it may not.

In the case of some cutting oils for ferrous mate-

Figure 4 – Railroad diesel engine piston showing heavy lacquer on piston skirt and around wrist pin losses. Note the flaking of the heavy deposit from the left hand piston pin boss.

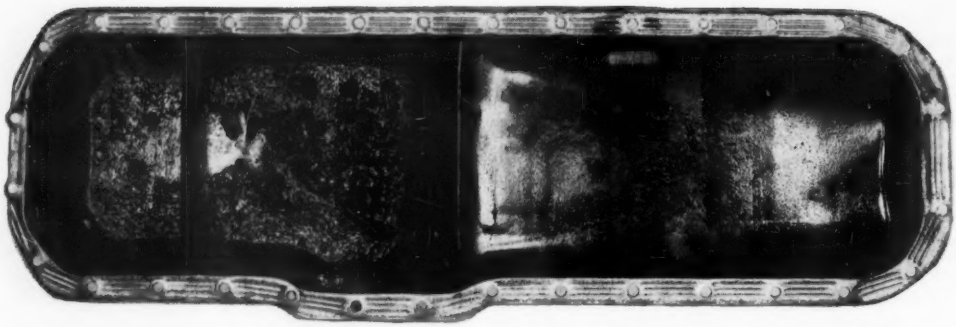

Figure 5 — Engine oil pan showing heavy accumulation of carbonaceous matter which has been deposited by the heavily contaminated oil.

rials, sulfur in an "active" form is purposely introduced into the oil in order to impart heavy duty, extreme pressure properties to the product. Since sulfur in this form will readily blacken copper, the product should obviously not be used for machining this metal. This is clearly shown by Figure 6 which illustrates a copper strip which has been immersed in a non-corrosive cutting fluid and one which has been immersed in an active sulfur-type oil. The effect of the reaction of the active sulfur in the latter oil is evidenced by the blackened strip. Heavy duty type gear oils frequently contain a sulfur additive which under normal conditions will not corrode copper, but will attack the metal at elevated temperatures. It would be unwise to use this type of product in a gear reducer equipped with a bronze worm gear which develops or is exposed to high temperatures. The suitability of a sulfur-containing product for use with copper or copper alloys is readily determined by the Copper Strip Corrosion Test.* Comparison of the test strip with the ASTM rating scale will indicate what corrosion, if any, may be expected at the temperature selected.

Naturally occurring sulfur compounds in well refined straight mineral oils sometimes act as oxidation inhibitors and are not corrosive to copper.

Heavy duty crankcase and circulating oils will often contain sulfur in combination with other elements which impart detergent-dispersant and antioxidant properties to the product.

The sulfur content of present day lubricants has little significance to the users of the products, with the exception of the "active" type cutting oils. In this case comparison between the active sulfur content of the used and unused oils gives an indication of the amount of E.P. agent remaining and hence the remaining useful life of the product.

Total sulfur content of a lubricant may be measured by either the Bomb or the High Temperature Method.

ANILINE POINT

The aniline point of a petroleum product is the temperature at which equal volumes of aniline and the product are mutually soluble. Aniline, an amine derivative of benzene, contains a ring structure and is more soluble in petroleum products composed of ring structures (aromatics and naphthenes) than those composed of chain structures (paraffins and isoparaffins) at the same temperature. A higher temperature is required to effect complete solution of the aniline in chain structure compounds. Since petroleum products are a mixture of ring and chain

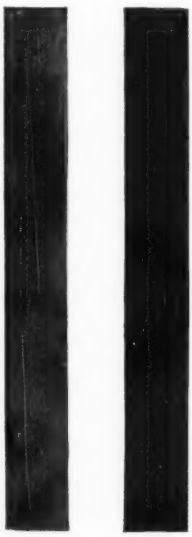

Figure 6 — Copper strips exposed to non-corrosive cutting fluid (left) and one containing active sulfur (right). Note blackening of the right hand strip by the action of active type sulfur.

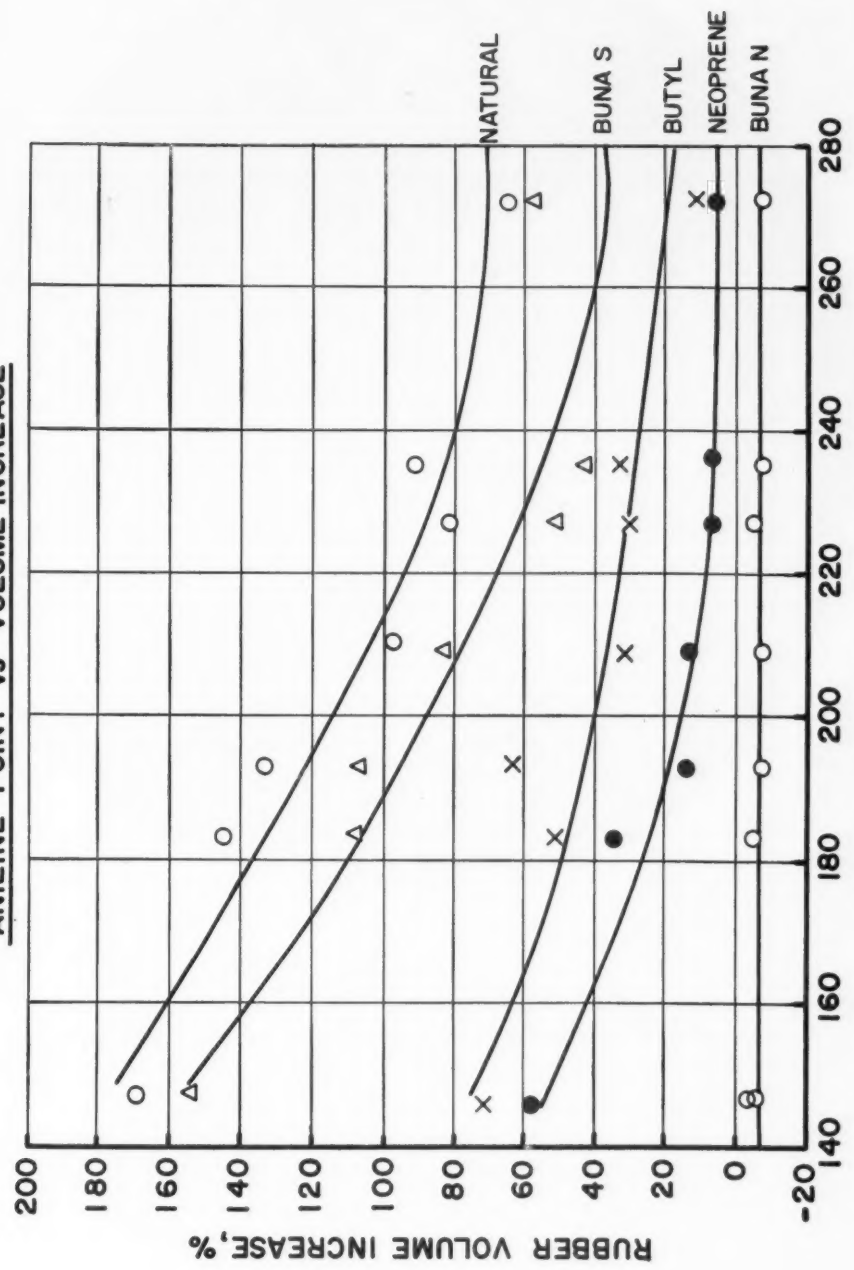

Figure 7 — Effect of oil aniline point on swelling of various types of rubber. (168 hours at 160°F.)

Figure 8 — Hydraulic accumulator diaphragm which failed as a result of excessive rubber softening and swelling.

compounds, the higher the temperature required to effect solution of the aniline in the sample, the greater the amount of chain compounds present; and conversely the lower the temperature, the greater the amount of ring products present.

Oil is usually the vehicle employed to carry the various components present in a printing ink. Printing ink manufacturers have found that naphthenic oils are more suitable for carrying these components and will therefore specify an oil with a low aniline point. In other special cases, a paraffinic oil is more desirable, therefore, an oil with a high aniline point is specified.

Wherever a seal is used to keep a petroleum product from leaking out of a piece of equipment, it is important to know what effect the oil will have on the seal material. Aniline point has been used to help predict this possible effect.

Rubber is one of the most widely used sealing materials today. Different types of rubber have varying sensitivity to oils of different aniline point values at a given temperature. Generally, for a given rubber formulation at a fixed temperature, the lower the aniline point of the oil, the greater the change in volume experienced. A graph of rubber volume change versus oil aniline point can be of great value in designing rubber seals for machinery. Such a graph is readily constructed by conducting rubber swelling tests on the particular rubber formulation in question with oils of increasing aniline point.

Results of a series of tests on specific formulations of several different types of rubber are shown in Figure 7. It can be readily seen from this graph that of the specific formulations tested, natural rubber was the most sensitive while Buna N was the least affected.

It is obvious that an oil seal surrounding a rotating shaft could be seriously distressed were it composed of natural rubber in contact with an oil having an aniline point of 170°F. If the seal somehow survived the large amount of swelling, and the oil in the unit was later replaced by one with an aniline point of 240°F., such a large amount of shrinkage could occur that the seal would no longer be effective, resulting in rapid leakage of oil and possible unit failure.

Similar difficulties can occur in other parts made primarily of rubber. Figure 8 illustrates a hydraulic system accumulator diaphragm which has failed because of softening and swelling of the rubber caused by an unsatisfactory hydraulic fluid.

Although aniline point is useful in estimating the effect of petroleum products on sealing materials, it should be borne in mind that temperature also has a marked effect on volume changes of sealing materials. Furthermore, the test can be misleading since oils of the same aniline point may have different hydrocarbon compositions which would alter considerably their actual effect on sealing materials.

INTERFACIAL TENSION

Interfacial tension ("IFT") is determined by measuring the force required to pull a platinum ring through an oil-water interface as shown in Figure 9. The test is usually used only on clear, straight mineral or rust-and-oxidation ("R&O") inhibited circulating and insulating oils. It is virtually never used on detergent-dispersant crankcase oils. The test is particularly noted for its great sensitivity to even minute amounts of foreign matter which may be present in an oil. It is this extreme sensitivity to minute (and in most cases inconsequential) amounts of

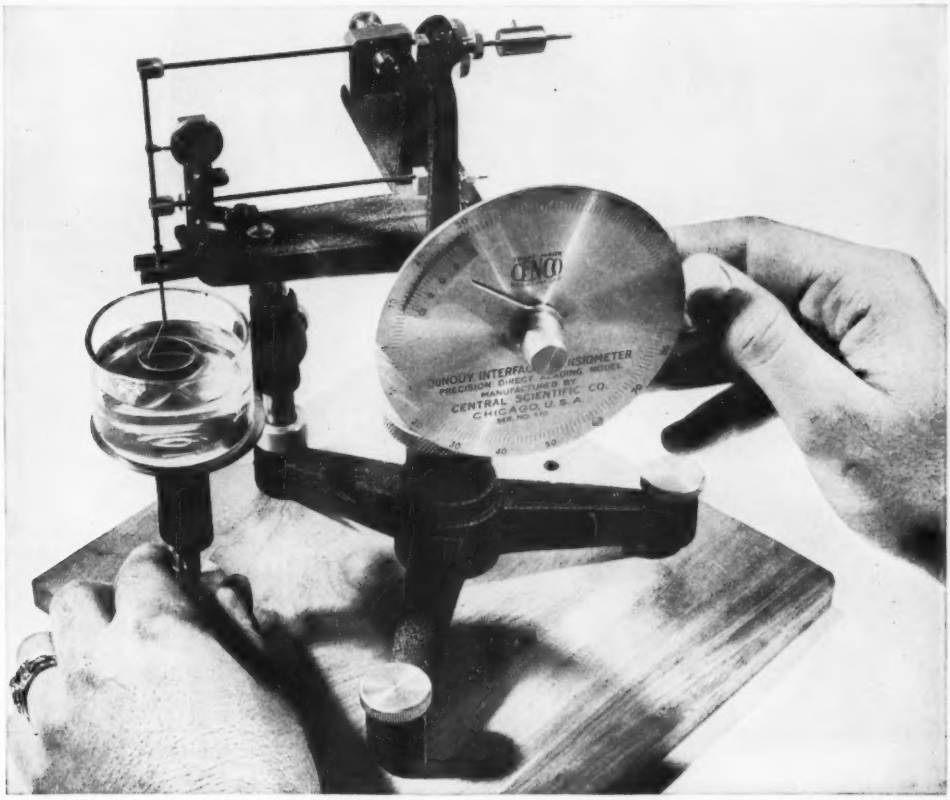

Figure 9 — An interfacial tensiometer. Note that the platinum ring is just about to break away from the oil — water interface.

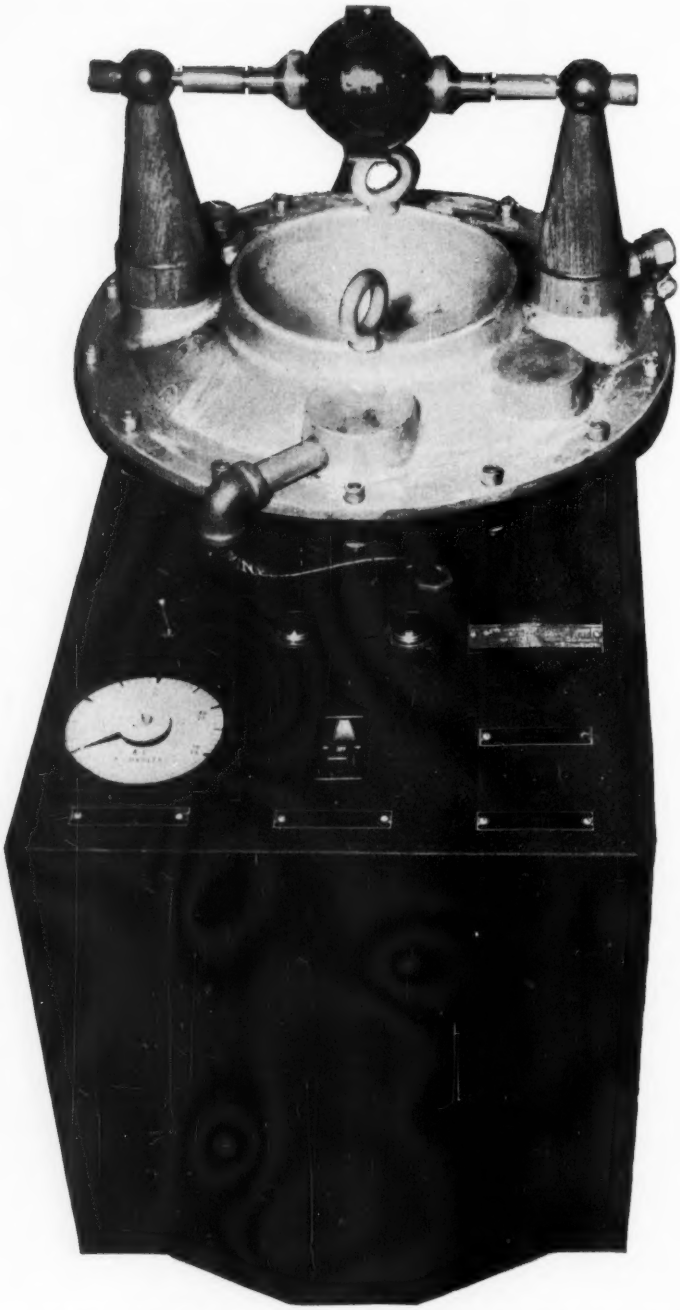

Figure 10 — Dielectric strength machine. The oil sample and electrodes are contained in the dark colored spherical cup at top center.

contaminants that has prevented the test from being more widely used than it is.

Interfacial tension has been used by steam turbine and transformer operators in an effort to determine the point at which oxidation of the oil will just start to occur. It is possible to determine this point approximately since as oxidation of oil progresses, hydrophilic compounds are formed which tend to lower the interfacial tension. This frequently precedes the formation of acidic material. It has been reported by users of uninhibited transformer oils that no sludge was found where the IFT value of the oil was above 24 while in every unit where the IFT was below 14, sludge was found. Turbine operators have indicated that sludging of an inhibited turbine oil, whose initial IFT was 30-35, could be expected when the value dropped to 18. In every instance, however, the units from which these values were obtained were kept under close observation to obviate the possibility of contamination and a very detailed history was maintained on each one.

Not only will minute contamination lower the IFT value (which for a straight mineral oil is 40 to 50 dynes per centimeter) but the addition of rust and oxidation inhibitors will in many cases drop it well below 15. Under service conditions, the oil would rise in IFT as the oxidation inhibitor is consumed to perhaps 35 and then start to decline again. The presence of even trace amounts of water, however, would immediately drop the value to perhaps 10.

This extreme sensitivity to water has been utilized to some extent as a "go, no-go" test for refrigerator and transformer oils where as previously noted virtual absence of moisture is a requirement.

It can, therefore, be seen that the sensitivity of this test has precluded its being more widely used than it is at present. Caution should be observed in interpreting IFT test values on any used oil.

DIELECTRIC STRENGTH

Petroleum oils have wide application as insulating media and heat transfer agents in large transformers, electrical switching gear, submersible pumps, oil-filled cables, etc. While oil in a pure condition is an extremely poor conductor of electricity (a good insulator), it becomes a better conductor in direct proportion to the type and amount of contaminants which may accumulate in it.

Many tests have been used in the past such as the A.C. Breakdown, D.C. Breakdown, Impulse Breakdown, etc., to determine an oil's insulating ability. At the present time Dielectric Strength is the most widely used test in the United States to determine this property. A machine used to conduct this test is shown in Figure 10.

The factor that most frequently affects the dielectric strength of an oil is its moisture content. To complicate matters further, it has been found that *dissolved* moisture has very little effect on this property while free water of the same magnitude can markedly lower the dielectric strength. In general, insulating oils containing more than 100 ppm free water have greatly reduced dielectric strengths.

Other contaminants such as dust, dirt, oil deterioration products, etc., while not as frequently encountered as water, will also reduce an oil's insulating ability as measured by the dielectric strength test. At the present time, oils with a dielectric strength of 25 KV (kilovolts) satisfy most electrical equipment requirements. The greatest danger of a significantly lower dielectric strength of an oil is the ever present hazard of a possible flash-over in the equipment wherein it is installed. This would, of course, result in a unit failure, interruption of service, and possibly a fire.

While the dielectric strength test is not useful in predicting the ultimate life span of an insulating oil, it is useful in determining its insulating ability at the time the unit is sampled.

Because of its sensitivity to water, the test is also used to check the dryness of refrigeration oils. A value of 21 KV is indicative of the fact that the oil has a low enough moisture content to function satisfactorily in a refrigeration system.

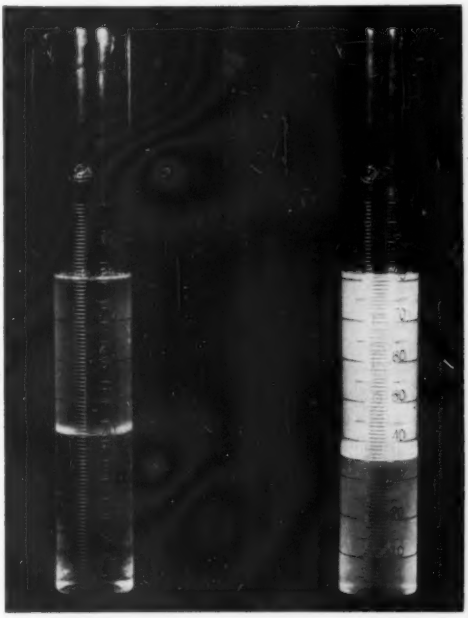

Figure 11 — Examples of turbine oil having good and poor water separating characteristics. Sample on the left separated completely in five minutes while that on the right did not separate completely even after one hour.

TURBINE OIL EMULSION TEST

While water, with some exceptions, is not desirable in petroleum products, there are some applications where its contact with a circulating oil is extremely difficult to avoid. In such instances it is customary to employ an oil which will readily separate from water.

A test which is widely used for measuring the ability of oil and water to separate from each other is known as the "Emulsion Characteristics of Steam-Turbine Oils". Figure 11 shows samples of two turbine oils which have good and poor water separating characteristics as determined by this test. The left hand sample has shown complete separation of the water from this oil while the right hand sample still shows considerable emulsion.

As the name of the test indicates, it is generally used for steam turbine oils. In this service steam and water frequently come into contact with the oil and in most installations, the water is removed from the oil by settling. If the oil, however, takes 30 minutes to separate from the water, and the system is designed to provide only 15 minutes "rest time" for the oil, emulsion, if formed, will not be completely separated. In such cases, either additional settling would have to be provided for the oil or a centrifuge installed. The same situation holds true for any circulating or hydraulic system.

On the other hand, a system may have been adequately designed but has been rendered ineffective because the oil may have become accidentally contaminated with a fatty material or a heavy duty automotive crankcase oil; or because of an overly extended long service period, an appreciable increase in the oxidation product level may have occurred. These materials, depending upon their concentration, will materially affect the ability of oil and water to separate from each other. The emulsion test is useful in such instances in evaluating the condition of the oil from the standpoint of water separation and whether or not the oil should be drained from the system.

SUMMARY

While the foregoing paragraphs have discussed the significance of specific tests at some length, it is not implied that an individual test will give the complete answer on a specific problem which may be encountered in everyday use. The tests discussed are usually conducted in association with other petroleum test procedures. The information derived therefrom is carefully evaluated by the petroleum technologist in conjunction with the conditions under which the product in question was employed, the place in the unit from which the sample was obtained, and previous experience with similar products and units in order to reach a logical conclusion.

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If further information is desired regarding the detailed procedures under which the previously discussed tests are conducted, the reader is referred to the American Society for Testing Materials Standards:

Water by Centrifuge
(Water and Sediment by Means of Centrifuge, ASTM D-96)

Water by Distillation
(Water in Petroleum Products and Other Bituminous Materials ASTM D-95)

Water by Karl Fischer Method
(Water in Insulation Liquids — Karl Fischer Method, ASTM D-1533)

Pentane and Benzene Insolubles
(Normal Pentane and Benzene Insolubles in Used Lubricating Oils ASTM D-893)

Precipitation Number
(Precipitation Number of Lubricating Oils ASTM D-91)

Copper Strip Corrosion
(Copper Corrosion by Petroleum Products ASTM D-130)

Bomb Sulfur
(Sulfur in Petroleum Products and Lubricants by the Bomb Method ASTM D-129)

High Temperature Sulfur
(Sulfur in Petroleum Products by the Rapid High-Temperature Combustion Method ASTM D-1552)

Aniline Point
(Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents ASTM D-611)

Rubber Swell
(Change in Properties of Elastomeric Vulcanizates Resulting From Immersion in Liquids ASTM D-471)

Interfacial Tension
(Interfacial Tension of Oil Against Water by the Ring Method ASTM D-971)

Dielectric Strength
(Dielectric Strength of Insulating Oil of Petroleum Origin ASTM D-877)

Turbine Oil Emulsion
(Emulsion Characteristics of Steam-Turbine Oils ASTM D-1401)

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